turns on its axis. A 60-foot pendulum, suspended from the centre of the dome, will be set swinging through a long arc, repeating the celebrated experiment of Foucault. The swinging pendulum will mark an invariable direction in space, and as the earth of the building revolves beneath it, rotation will be plainly shown by the steady change in direction of the pendulum's swing over a divided arc.

Two great phenomena of Nature, the sun and the rotation of the earth, are thus to be exhibited. Other phenomena to be demonstrated in striking form in the central rotunda are magnetic storms, earthquakes, gravitational pull of small masses, the pressure of light, the visible growth of plants, swimming infusorians in a drop of ditch water, living bacteria, and other interesting phenomena.

In the seven exhibition rooms surrounding the central rotunda, the latest results of scientific and industrial research will be illustrated. One room will be set aside for the use of Government bureaus, another for industrial research laboratories, others for the laboratories, observatories, and research institutes of universities and other institutions. The newest discoveries and advances in the mathematical, physical, and biological sciences and their applications will be shown in this living museum, in which the exhibits will be constantly changing with the progress of science. One week there may be displayed the latest forms of radio-telephony; the next perhaps a set of psychological tests or a new find of fossils or a series of synthetic chemical compounds. Such a mutating museum will continue to attract and instruct large numbers of visitors and residents.

We call it the building for the National Academy of Sciences and the National Research Council, but in reality it should be the national home of science in America, and will be looked upon by our fellow-citizens and the world at large as the place where the creative mind will be able to do much to bring about a better existence for the future people of the world, for it is to their enlightenment and advancement that it will be dedicated.

The Internal Combustion Engine.[1]

By Prof. W. E. DALBY, F.R.S.

The Influence of the Internal Combustion Engine.

TO engineers the terms horse-power and horse-power hour have strictly technical meanings. They can be illustrated by comparing the weight and efficiency of an aircraft engine and a locomotive engine. An aircraft engine can be built with about 2½ lbs. of metal per horse-power as against approximately 250 lbs. of metal per horse-power in a locomotive engine. An aircraft engine requires about ¾ lb. of fuel oil per H.P. hour as against 3 lbs. of coal per H.P. hour used by the locomotive engine, in addition to which the locomotive engine must carry about 3 gallons of water per H.P. hour. All these, of course, are round figures. It is the extreme lightness of the petrol engine in relation to its power which has made it possible to develope aircraft.

An internal combustion engine of the Diesel type is built to use heavy oils, and has provided a prime mover by means of which the submarine was able to develop so considerably during the war. Thus the internal combustion engine helped to sink our food ships, but at the same time helped to save the situation by driving the agricultural tractor. Few, perhaps, realise fully how serious was our position in 1917. Horses were required for the Army and were being taken from the farms; but the agricultural tractor replaced them at the plough and thus made it possible to maintain the necessary food supplies.

Probably the greatest effect of the internal combustion engine on our national life is its influence on road transport. Standing at Hyde Park Corner twenty years ago a motor car would have excited notice; standing there to-day it is almost true to say that the horse-drawn vehicle has practically disappeared. The internal combustion engine is displacing the horse from the streets, and is even causing the railway companies grave concern. The chairman of one of them stated at the last half-yearly meeting that the companies had lost 9 million tons of goods, and 6 million passengers to the motor lorry and the motor car. This is a remarkable achievement for the small 16-20 H.P. internal combustion engine which is fitted in these vehicles. During 1921 about 800,000 licences were issued to vehicles propelled by internal combustion engines and the tax on them amounted to about ten million pounds.

These brief considerations indicate how profound has been and is the influence of the internal combustion engine in shaping our destinies. It has conquered the air, and has given us a prime mover useful in farming and in transport. It is influencing the policy of our railways, and will shortly so transform our outlook and our modes of life that men of to-day will appear to be separated from their boyhood not by a few decades but by a few centuries.

Some Problems of the Internal Combustion Engine.

Considering combustion from the point of view of the Kinetic Theory of gases, but without attempting to explain the nature of the differential attraction between molecules, most of the energy developed in the cylinder of an internal combustion engine arises from the fact that oxygen combines with carbon and hydrogen to develop large quantities of heat. The function of the engine is to convert as much as possible of this heat into mechanical work.

It can be deduced by the laws of gases that the molecules at 22° C. and atmospheric pressure require 729 times the volume they occupied as a liquid. This can be illustrated by "air patterns" representing the distribution of molecules in the air. Actually the molecules are flying about at a high velocity across the vessel the sides of which they are continually bombarding and therefore exerting pressure on them.

Calculation from the kinetic theory of gases shows that at 22° C. the oxygen molecules in the air are flying at a velocity of about 1600 ft. per second, the nitrogen molecules at about 1700 ft. per second. This velocity is not the mean but the square root of the mean square of the actual velocities of the particles. The molecules collide and zig-zag about in the enclosing vessel so that it is only by imagination that we are able to conceive them as standing still and forming a pattern something like the pattern on a wall-paper.

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[1] From a Discourse delivered at the Royal Institution on Friday, May 26.

When a spark is passed in a mixture of air and a hydrocarbon such as pentane a re-arrangement of the molecules takes place. The 5 atoms of carbon in the pentane molecule produce 5 molecules of carbon dioxide; 12 atoms of hydrogen produce 6 molecules of steam. Before ignition there are 41 molecules including 32 molecules of nitrogen. After the explosion there are 43 molecules, nitrogen taking no part in the change. Oxygen ceases to exist as a separate entity. The result is that every pound of pentane so transformed produces 10,000 lb. calories of heat.

The immediate effect of this production of heat is to increase the velocity of the flying molecules. The actual velocity of the products of combustion in the vessel depends on the mean temperature. Direct measurement of the temperatures of the working charge of a gas engine gives 2570° abs. as a reasonable temperature from which to calculate molecular velocities. At this temperature the carbon dioxide molecules are moving at 3950 ft. per second, the steam molecules at 6166 ft. per second, and the nitrogen molecules at 4950 ft. per second; these numbers being the square roots of the mean squares of the actual velocities.

The next point for consideration is the time taken to effect this change. The time-interval taken by oxygen to combine with carbon and hydrogen lies along a time scale beginning with a detonation and ending with slow burning. In a mixture of air and pentane the oxygen molecules are a long way, on the average, from the carbon and hydrogen of the pentane molecule, and also the freedom of action of the oxygen molecules is clogged by the inert nitrogen present, but the rapidity with which oxygen can combine when the circumstances are favourable is shown by nitro-glycerine.

Chemists have discovered how to produce this nitro-glycerine molecule so that oxygen lies side by side with the carbon and the hydrogen. Its action is unclogged by any other substance, and the molecular distances have been annihilated, or perhaps it would be better to say that they have become atomic distances. Moreover, the molecule contains almost the exact quantity of carbon and hydrogen required to satisfy the oxygen present. As Lord Moulton once put it, it is a case of the lion and the lamb lying down together. A mechanical shock causes an immediate transformation—the lion devours the lamb; and the time-interval for the meal is so short that it is not measurable. This is called a detonation. Chemists have by their researches shown how to combine nitro-glycerine with other substances in order to control the rate of combustion. Engineers are also trying to get control of the rate of combustion of some of the mixtures used in the internal combustion engine. Thus the chemist and the engineer are working in different parts of the same wide field of research.

Experiments initiated by Sir Dugald Clerk are now proceeding at the National Physical Laboratory under the general supervision of the Aeronautical Research Committee for the Air Ministry. Apparatus of the most refined nature has been devised, and the research is being carried out by Mr. Fenning. Various combustible mixtures are made up in a bomb. These are exploded and then the time taken for the chemical combination to take place is recorded. Two results may be mentioned: a mixture of one part by volume of hydrogen, 2½ parts by volume of air, was compressed to 64 lbs. per sq. inch and then exploded. Between the passage of the spark and the beginning of the rise of pressure about four-thousandths of a second elapsed. The combination was complete in about the same interval of time. In another experiment the mixture was diluted with one part of hydrogen and 6 parts of air; this caused delay in the combination, which took six-hundredths of a second to complete. In such diluted mixtures the energy has to be shared by all the molecules which do not take part in the change.

The engineer is faced with two problems: the problem of a too rapid combustion, becoming a detonation, and the problem of a combustion too slow for complete combustion at high speeds.

In practice the turbulence and eddies caused by the rapid admission of a charge through the narrow annulus of an open admission valve results in quickening the rate of combustion, and it is owing to this cause that the gas engine can run at speeds greater than those corresponding to the measured rate of flame propagation for an efficient mixture. Sir Dugald Clerk found a striking difference in the area of indicator diagrams according to whether the mixture was exploded immediately after the admission valve was closed or whether it was exploded after precautions had been taken to damp out the eddies.

Among the problems arising from running internal combustion engines at high speeds is that of torsional oscillations, and synchronous oscillations. There is also the balancing problem. The four-cylinder petrol engine is usually constructed so that it is perfectly balanced for primary forces and couples, but gives the maximum error for unbalanced secondary forces. At certain speeds a model of this type suspended from springs will oscillate twice as fast as the speed of rotation of the engine, while at the same speed and on the same springs a model, balanced to eliminate the secondary forces, will run steadily at all speeds.

Other problems have also to be considered. Accurate records of the pressure-volume relation in the internal combustion engine must be obtained, and the difficulties are increased owing to the high speed at which the cycles take place. The direct measurement of temperature is also a difficult matter, and there are various fuel problems.

Sufficient has been said to show that the future of the internal combustion engine is not settled; it is full of problems requiring continuous and laborious research. The question is what provision has been made for this research. Before the war purely scientific research on the internal combustion engine was focussed largely in the Research Committee of the British Association established at the Dublin meeting in 1908. This Committee was the only one of its kind, and the work was carried on vigorously until the war under the successive distinguished chairmen, Sir William Preece and Sir Dugald Clerk. The Committee is still in existence. There is also the Research Laboratory at Shoreham under the direction of Mr. H. R. Ricardo, himself a distinguished scientific investigator.

During the war official organisations have been established, and now the Department of Scientific and Industrial Research provides aid in money, apparatus, advice, and encouragement to any individual worker who has ideas and is qualified to carry on a research alone or under direction. This is a great national asset. But above all, so far as the petrol engine is concerned, there is the powerful organisation for Research within the Air Ministry itself, generally under the supervision of Air-Marshal Sir Geoffrey Salmond (known as the Director-General of Supply and Research), but under the immediate direction of Brigadier-General Bagnall-Wild, officially known as the Director of Research. The Air Ministry is advised by the Aeronautical Research Committee under the chairmanship of Sir Richard Glazebrook. This Committee has grown from the old Aeronautical Advisory Committee of the late Lord Raleigh. Work of the highest scientific value is now in progress at the National Physical Laboratory, at Farnborough, and at other places under the direction of the Ministry.

All I have done here is to hint at some of the work now going on at the National Physical Laboratory; it would take a whole evening merely to epitomise the researches in progress at that institution. Farnborough is now entirely a research establishment in its widest sense, for it is organised both for laboratory and for full-scale work. Work on the internal combustion engine has reached a magnitude and an intensity undreamt of before the war. The war has, in fact, shown that the internal combustion engine instead of being a convenient prime mover to put in our motor cars, to drive our workshops, or even our ships, has become an engine vital to our very existence. The Aeronautical Research Committee realises this, and the Air Ministry also. Let us hope that the nation will realise it too, and that in the need and passion for economy our legislators will not starve research on this vital national prime mover.

The Hull Meeting of the British Association.

LOCAL ARRANGEMENTS.

ARRANGEMENTS are well in hand in connexion with the meeting of the British Association for the Advancement of Science at Hull, September 6-13. Hull is particularly well provided with suitable rooms for the evening discourses, public lectures, and sectional meetings. Its large City Hall, centrally situated, accommodates three thousand people, and trams for every part of the town start at its doors. In this the inaugural meeting on Wednesday, September 6, will be held at which Sir Charles S. Sherrington (President of the Royal Society) will deliver his presidential address entitled "Some Aspects of Animal Mechanism." On the following day the City Hall will be the scene of the Lord Mayor's reception.

Hull's new magnificent Guildhall provides an excellent reception-room, adjoining which the banqueting chamber makes a very fine lounge and writing-room. On the same floor are suitable rooms for the various officers of the Association, the press bureau, the meteorological demonstration given by the Air Ministry, etc. This last named will be very welcome in the reception room, where it will be seen by everybody, and in an adjoining room the methods of preparing the chart will be available to the members.

Across the road from the reception-room are the British Association refreshment rooms, the Queen's Hall (Section F (Economics) and joint meetings). Section A (Mathematics) meets in the Central Hall, Pryme Street; B (Chemistry) in Waltham Street; C (Geology) and H (Anthropology) in the Museum and Royal Institution; D (Zoology), E (Geography), K (Botany), and M (Agriculture) in the new Art School; I (Physiology) in the Church Institute; J (Psychology) in the Albion Hall; and L (Education) in the Lecture Hall, Jarratt Street. All these buildings are within three minutes' walk from the terminus of the various tram routes in the City Square.

The Local Committee is providing each member with a small badge, which has been artistically designed and will serve as a more convenient means of identification than the somewhat cumbersome members' ticket (this latter, however, is this year to be waistcoat-pocket size and once more includes, as formerly, a map of the meeting-rooms). Each badge bears the number of the member's card, so that a reference to the index at the end of the list of members will enable the identity of any particular member to be ascertained, if desired.

With regard to the accommodation, while it is not expected that there will be any difficulty in providing for as many members as care to visit the city, the hotel accommodation which will be available for visitors is exceedingly limited. This year, therefore, a list of hotels and lodgings will not be prepared, but a special committee is sitting with the object of meeting the requirements of the members. In this connexion rooms are being provided at Bridlington, Hornsea, Withernsea, Beverley, Cottingham, Brough, Ferriby, Hessle, and other places in the immediate vicinity, but the provision of special late trains and of exceptionally favourable weekly contract tickets for this meeting will help considerably. It is desired to impress upon intending visitors to the Hull meeting the necessity of filling in the cards on the back of their preliminary programme, and returning them to the Secretary at the earliest possible moment, in order to prevent unnecessary trouble, which will certainly be caused if members arrive at the meeting without having previously notified their intention of being present. This warning seems particularly necessary, as several members have intimated their intention of being present, but neither state that they have found accommodation nor that they wish accommodation to be found for them. Those who have applied will receive particulars of their rooms shortly.

In a previous article reference was made to the various presidential addresses, with the exception of